SADLER

The Automatic Block Signal System on American Railroads

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THE AUTOMATIC BLOCK SIGNAL SYSTEM ON AMERICAN RAILROADS

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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ENTITLED "THE AUTOMATIC BLOCK SIGNAL SYSTEM ON AMERICAN RAILROADS".

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

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THE AUTOMATIC BLOCK SIGNAL SYSTEM ON AMERICAN RAILROADS.

I. INTRODUCTION.

PURPOSE. The purpose of this thesis is to investigate the reasons for the adoption of the automatic block signal system as a standard on American railroads, and to determine whether or not it fulfills the various requirements of our modern railroads. In doing this it will be necessary to narrate the history of the automatic block signal system, after which will be given a description of the different block systems in use, concluding with a comparison of the several systems and a statement concerning the present and future status of the automatic block system in America.

SCOPE. In narrating the history of the subject it will be the object, first, to recall the early progress in railroad signaling, not limiting the discussion to this country alone, but granting liberal attention to foreign countries; second, to show the development of the system in America to meet the various needs of the railroads; and third, to mention the legal steps which have been taken to keep apace with the corresponding engineering progress of the age.

The history of the subject will be followed by a description of the various block signal systems in use in the United States. The operation of the telegraphic-block will be taken up first, and the adaptability and essential details of this par-

ticular system to modern practice will be discussed. The next in order will be the controlled manual, which divides itself readily into the two divisions of the staff system and the Sykes system. The operation of the staff system will be explained, and its peculiar advantages brought out. Under this same head will be noted the Sykes system, an explanation being offered of the machine used and the operation of the system under traffic. Finally, the automatic block system will be described. The various operations during the movement of trains will be brought out in detail, the functions of the several circuits will be shown, and a few particularly interesting adaptations of the system to peculiar conditions will be mentioned.

A comparison of the advantages and disadvantages of the several systems will follow the description of operation. The relative cost of installation and maintenance will be given, although a major part of the discussion will be devoted to the corresponding effects of the personal equation on the efficiency of these different methods of blocking. The factors of loyalty and discipline of the train crews, and the resulting effect upon efficiency, also will be discussed.

It will be the object of the conclusion to decide whether the performance of the automatic system warrants its further adoption in preference to the other block systems.

IMPORTANCE. Block signaling, in some form, has long been recognized as essential to the safe and efficient operation of railroad traffic. It is well to realize that in modern railway practice, efficiency of operation is as important a factor

as safety. That is to say that traffic must be moved expeditiously, and with such efficiency that a sufficient margin of profit is left available to encourage capital to invest in railroad enterprises. The railroad must first exist, and it must be made to transport enough goods and persons to meet the country's needs. In doing this it is necessary that human life be conserved as much as possible.

For the great majority of cases some form of a block signal system is absolutely indispensible. Of course it is conceivable that with a sufficiently large number of tracks, and with low enough speeds, a type of a permissive form of timetable schedule could be used whereby trains could meet at stated stations or sidings to pass or overtake one-another. Such a type could probably work with a satisfactory degree of safety, but it would be seriously hampered by the adverse weather conditions, and the sharp curves, tunnels, and grades of our mountainous districts, where it is very difficult for the engine driver to keep a lookout for obstructions.

As far as the efficiency of such a system is concerned, however, let us consider the enormous tonnage moving daily between New York and Chicago. On parts of the New York Central alone the daily trains average one a minute for several hours at a time. What kind of a time-card schedule could be constructed which would accomodate such a density of traffic on less than a dozen tracks? Careful thought will emphasize the fact that the question for our American roads to decide is not, "Shall we use block signaling or not?" but that the question is, "What type of block signaling shall we adopt?"

II. HISTORY.

The total length of railways in 1830 was 23 miles, while in 1840 the number had increased to 2,818. It was during this decade that the signal made its real advent into the American railroad field. Considering the fact that 1829 is the year of the first practical steam locomotive in America, it is apparent that, from the first, the need of block signaling was realized. The Pennsylvania Railroad Company asserts that the Newcastle and Frenchtown Railroad installed the first form of block in America. This road, which is now a part of the Pennsylvania system, was about 20 miles long. It appears that there were five stations on the road, and that at each station was located a pole and ball arrangement. When an operator wished to signal that a train had left his station, and that all was well, he raised a white ball to the top of his pole. The next operator saw the ball through his telescope, and sent the news on by putting his own white ball at half mast. A black ball served to convey news of interruptions to service. The system was probably not extensively adopted; at any rate, there is little information obtainable concerning it.

The inherent advantages of telegraphy were destined to place it in an indispensable place in the railroad world, and, as England was the scene of intense inventive activity in this direction, the English railways early took a prominent place in the development of telegraphy and, later, in its application to signaling.

It is stated upon good authority that in December, 1839,

the Great Western Railway of England announced the passage of its trains between Paddington and West Drayton by telegraph, this apparently being the first noteworthy application of electricity to the conveyance of railroad messages. The development which followed is, possibly, quite interesting.

The original conductors consisted of copper wires running a few inches above the ground along the railway. This arrangement gave place to the telegraph poles in 1842. Two years later William F. Cooke advanced a system for indicating the location of trains. He had several magnetic needles at each station, and the position of these needles served as an indication of the position of the train in question, but the large number of separate circuits and needles required emphasized the awkwardness of the plan. Some little while later the London and Northwestern adopted a simplified arrangement of the Cooke plan. The number of circuits was reduced to three, two for a double needle, and one for an alarm bell.

It is important to note that the first signal systems were prone to use a time interval as a unit, by holding a train up until five or ten minutes had elapsed since the last train had gone in that particular direction. The limit to both the safety and the capacity of traffic under such a method is probably self-evident. In the application of this modified form of the Cooke plan, however, the unit was changed from the time to the distance, the trains now being kept a specified distance apart by the use of the block.

In 1852, the year in which Chicago was reached by the

westward extension of the railroads across Indiana, Mr. Tyler of England invented his first block signal instrument. As first devised this instrument was automatic. The passage of the train past a point established two circuits by means of the rail depressing under the train. One circuit sent the signal at that point to "line occupied," while the other circuit sent the preceding signal to "line clear." The establishment of these circuits by the depression of the rail soon gave place to a manual system where the operation was done by hand. It is stated that the system was adopted by several Scottish and English railroads. Activity in the various branches of signaling now became lax for a number of years, and it was not until after the Civil War in the United States that any material advances or changes took place.

It is stated that the New York and Philadelphia Division of the United Railroads of New Jersey installed the telegraphic block in 1865. The system had certain disadvantages, and in spite of its widespread adoption it was the basis of diversified investigation.

About this time inventors were laboring industriously on the automatic block. The chief among these workers, perhaps, was Thomas S. Hall. He was a native of Connecticut. Most of his work was done in New England. In 1871, about six years after the installation of the first telegraphic block, Hall introduced the first successful automatic block system in this country. The first form was constructed with a wire circuit as a basis. The passage of a train by a certain point threw a lever at that place by means of the car wheels, and a circuit was thus established which sent a nearby signal to danger. After the train had passed

the point, the lever sprang back to its normal position, the signal circuit was broken, and the signal indicator was held at danger until the train had left the block which it was just entering when the signal fell to danger.

In 1873 a system was tried which used the axles of the cars as circuit closers, while two years later the deflection of rails was depended upon to close the circuit. All of these systems, however, have since become obsolete, and one authority attributes the reason to the fact that since each method used a wire circuit, the induced currents from electric storms threw the signals to clear and thus introduced a remarkable degree of uncertainty.

For a few years previous to 1875 Spang did considerable work in his effort to combine a track circuit and an electro-magnet in one system, for he thought he recognized in such a combination a chance for eliminating the disadvantages of the wire circuits. He proposed to use regular track circuits, which should be short-circuited through the axles by the passage of a train. This shunting of the battery circuit from the electro-magnet caused a movement of the magnet and a resulting establishment of a local circuit, which moved the signal. The indicating medium was an enclosed disc of the banjo type, the semaphore not being in extensive use at that time. In 1872 Robinson conceived of a constantly closed track circuit using a gravity battery, and after seven years of trial and development he induced the Boston and Maine Railroad to use it on a part of their Fitchburg division.

In 1875 an Englishman by the name of Sykes invented

the lock and block system. It is a form of the controlled manual system, the operator at each block throwing his own signals. The apparatus at the signal lever was so constructed that the operator at the next block could electrically lock the first man's signal if he knew there was a train in the block. So very successful have been some forms of this system that several roads with dense traffic are still using it to a large extent.

During 1880 to 1890, in which decade the United States opened the greatest extension of railway mileage which the world has ever witnessed, the electro-pneumatic system was brought forward and perfected. It is extensively used on the Pennsylvania and other roads on terminal work. In 1897 efficient electric motors were developed which could run on a low voltage, and about the same time economical types of primary batteries were introduced. The result was that the electric semaphore proved a distinct success and it has come to be the standard indicator in practically all block signal systems.

III. DESCRIPTION OF THE VARIOUS BLOCK SIGNAL SYSTEMS.

TELEGRAPHIC BLOCK. Any block signal system in which the operator moves the signals by hand is called a "manual block system." Should the system be under the control of another operator so that the first operator is not at liberty to move his signal at will, the signal system is called the "controlled manual." Where the first operator merely requires the permission to act from another operator, the system is called the manual block system. Since the telegraphic block system is the simplest in operation, and generally the easiest understood, a limited amount of description should suffice to give a clear understanding of the subject.

Let us assume that a single track road running across the country has three adjacent stations. These stations are named Skyland, Fielding and Highgate, the above order being observed in traveling from Skyland westward along the line. The distance between successive stations is probably four miles. In order to operate traffic under a telegraphic block system, wire communication is established along the route whereby orders may be sent from one operator to the dispatcher, or to another operator. At the end of each block are located home and distance signals, and a station house in which are located the levers controlling these signals. Part of the station house is used as the operator's office.

As a train comes westward and approaches the Fielding station it whistles. The operator at Fielding telephones or

telegraphs to Highgate, the next station west, that a train is approaching Fielding from Skyland, and asks for clearance of the train from Fielding to Highgate. The operator at Highgate recalls whether there are any trains between Highgate and Fielding, and if he is confident that there is not, he gives clearance to the train approaching Fielding. The operator at Fielding throws his signal to clear, and the train enters the block without stopping at Fielding. As soon as the train is in the block, the signal is put at danger so no more trains will enter. The operator at Fielding then wires the station at Skyland, the operator at the east end of the block, that the train has come out of the block between them. As soon as the train has gone the operator at Fielding fills out a blank form stating time of arrival and departure of train, train number and minor details.

The telegraphic bell is one deviation from the above system. In this system all of the movements of trains are communicated by the use of bells. A standard code of signals is used throughout the line. The many combinations of long and short rings possible afford an opportunity to give almost any order by bells. As a train goes past a signal station, the operator may detect that there are no flags or lights on the rear end. He immediately knows that something is wrong, and he wires the operator ahead a given combination of rings which indicates that the rear signals on the last car are gone. The code even furnishes protection against loosely swinging side-doors on box cars, and against runaway engines. In short it is sufficiently broad to meet any conceivable emergency as well as to attend to the ordinary business of block signaling. A big advantage of

the telegraphic bell is that experience in telegraphy is not required.

Another deviation from the telegraphic block is the card system. The operator gets permission to give a train the clear signal into a block direct from the dispatcher. Upon receiving clearance from the dispatcher he fills out two duplicate cards. Each of these cards is fastened to a hoop, the home signal is put at "clear", and as the train comes through, the train crew catch the hoops with the card messages. It is unnecessary for the train to slow down to less than thirty miles an hour in order to pick up the hoops. The card gives the train crew permission to enter the block, and upon completion of their run, the engineer and conductor must each have a clearance card for every block which they went through. The cards can be either yellow or red. A red card is used when there is a train in the block already, and caution must be used in proceeding. The yellow card is used where the block is clear.

It is a strict order that the operator must return to his wire as soon as the train has gone and send a message of the train movement to the person who gave permission for ~~the~~ the train to enter the block. The railroad company usually requires that the number of train, character of makeup, and time of entering block be entered immediately upon a tabulated form, furnished to the operator. This furnishes useful data in the investigation of accidents.

CONTROLLED MANUAL. The second type of a block signal system is the controlled manual. In the telegraphic block system a certain degree of safety and efficiency of train operation was secured by putting a check upon the signal man. This check was the permission from the operator at the further end of the block, for the operator at the entrance to the block to clear the entrance signal. Many difficulties, however, might come up in this connection. The operator at the entrance was required to secure such permission before he cleared his signal, but as that was not a complete check, a serious accident might easily occur before the error was discovered. A mistakenorder, or a lapse of memory on the part of either operator, might occur which would result in an accident or delay to traffic. In order to reduce the application of the personal equation the controlled manual system was developed.

The controlled manual system differs in this respect from the telegraphic block system. The check on the correct position of the signals is a mechanical part of the signals themselves. To a considerable extent, then, carelessness in the operation of the signal is avoided. This check corresponds to the check in the telegraphic block, for in each case the agreement of two operators is expected for the movement of trains. The manner of locking and unlocking these signals may be one of several methods.

Two of the most important of these methods are the Sykes system and the electric staff system. It is stated that the Sykes system is the older and the more generally adopted, so the enumeration of its operation merits first consideration.

When an operator desires to free the signals at an adjoining station he pushes a plunger at his own station. For the sake of clearness we will say that the first operator is at station "B", while the second is at station "A". When "B" pushes the plunger in his instrument, an electric circuit to a machine at "A", the entrance to the block, is established. This machine at "B" is the one that locks the signals.

The electricity frees a catch on the machine and the lock rod falls from the lock bar, leaving the lock bar free to move. Suffice it is to state that now the operator at "A" can throw his signal. Should the operator at "B" release the locks on the wrong signal at "A", the signals are locked in that wrong position, and the consent of "A" is required before operator "B" can unlock those particular signals at "A". As soon as the train enters the block a track circuit is established. This circuit holds the signal at danger until the train leaves the block. When the train leaves the block "A-B", passing station "B", the control of the signals at "A" revert to operator at "B". Further operation then becomes a repetition of the steps described above.

Experience has shown that the Sykes system is not thoroughly adapted to the varying needs of heavy traffic, and it has undergone some radical changes in order to meet these varied demands put upon it. For instance, the Pennsylvania Railroad uses it in certain places. On a certain piece of single track near Cameron, Pennsylvania, it has developed an unique combination of absolute and permissive blocking. The instruments are so interlocked that while one train is in the block,

another train can not enter from the opposite direction. This is consistent with the principles of absolute blocking as set forth in the earlier pages of this treatise. On the other hand, the machines are wired up to give permissive blocking for "follow-up movements." Thus, when a train has entered the block and another train, perhaps a freight, comes up to the entrance to the block, the operators at each end get into communication with each other. If both operators are willing, the train is permitted to follow the preceding train into the block. Even for facing movements certain modifications of the Sykes system of absolute blocking are in use. Thus a train may enter the "exit end" of a block already occupied, with the intention of proceeding to a siding where the train first in the block is met. This becomes a case of permissive blocking, again.

The Sykes machines were adopted for the use of but one home and one distant signal at each switch. There are, however, many times, in cases of heavy traffic, when it is necessary to install a number of switches and crossovers, and under such conditions a more extended machine is necessary. The Coleman lock and block instrument represents such a development. One of the most extensive adoptions of this system is on the New York Central lines. Here a system of advance signals was used in connection with the home signals. As in the operation of the other controlled manual systems which have a track circuit, the instant the train passes the entrance to a block the signal there goes to danger. This signal was formerly at clear, in order to permit the train to enter the block, but it now remains at danger until the train has cleared the block. When there is

a switch lying between the home and distant signals, it is wired on a separate circuit to the machine at the station. When the switch is open, this separated circuit is so connected up that the home signal, which might otherwise be at clear, is kept at danger. The home signal is put at danger by shunting the home signal circuit. The home signal thus drops to danger by its own weight. Obviously this development may be extended so that any number of switches can be put on the same special circuit, and the opening of any one of the switches would send the home signal to danger. The New York Central Railroad offered this further modification in its Park Avenue Tunnel in New York City. It used a continuous track circuit instead of the broken circuit described above. The advance block signals were replaced by heavy alarm gongs and torpedo machines. This replacement of the advance block signals was probably not very successful, for there is no literature describing its practicability.

ELECTRIC TRAIN STAFF. The electric train staff is a very logical development of the earliest form of railroad signaling. As soon as the early railroads secured enough equipment to have two trains on the same "run", they were confronted with the problem of operating these two trains in opposite directions on a single track. When the two trains met, a live argument arose as to which train should proceed and which should back up. Several remedies were offered to meet the trouble. One remedy was to give the train reaching the half-way mark first, precedence over the other. The paramount disadvantage in such a system, however, was that a freight train would often make an express train to back up. A second and more popular method

consisted of the following:

For each block there was one talisman, and the train possessing that talisman had the right to proceed. As this was before the days of telegraphy, any train was reluctant to start out on the block without the talisman, for in case of meeting the train with the talisman it had to back up.

The development from this early system of the talisman to the present staff system is an answer made to meet the requirements of the increasing volume of traffic. Thus, with a greater number of trains going east than west, the talisman would usually be at the east entrance to the block. A west-bound train could always get the talisman without a long wait, if any at all. The east-bound trains, however, had to make long waits at the entrance to a block, waiting for one of the few trains in the opposite direction to return the talisman to their end of the block. One development to meet this case was the division of the talisman into several parts. Thus, when a number of trains from the same direction were held up at the end of a block together, they could proceed under one train order as soon as the single train from the other end brought the talisman along. This necessitated changing the talisman from the shape of a ring about the size of a horseshoe to that of an iron rod one inch in diameter and twenty inches long. This rod was now called a staff, and it was divisible into several parts as required above. Each one of the several trains took a part of the staff, and thus the entire number of trains had precedence over trains from the other direction.

With the introduction of telegraphy, however, some decided advances were possible. It soon became known that not only

could magnets at considerable distances be electrically operated to send messages, but the magnet could also be used to lock and unlock signal apparatus. We now pass directly to the essential parts of the modern machine. A machine is located at both "A" and "B", the two ends of the same block. There is telegraphic communication between the operators at "A" and "B". The two machines are so wired together that the electric results explained below can be obtained.

When a train desires to enter the block "A-B" at "A", operator "A" asks permission of "B". If operator "B" is confident that all is well he grants the request. "B" then moves a lever in his own machine which unlocks the door of the machine at "A". Operator "A" can then remove one staff and give it to the waiting train crew. As soon as the staff is removed, both instruments are locked, and it is impossible for either operator to unlock his own, or his neighbor's machine until that removed staff, which is now in the hands of the train crew, has been returned to the machine at "A", or else carried on and inserted in the station at "B".

For the greatest efficiency of operation it is not desirable that the train be required to stop at each station to pick up the staff. The way to save time is to have the train coming from "A" drop the staff for block "A-B" out of the cab window at station "B". At this point he can also pick up the staff for the next block without stopping. The way to do this is to put the staff in a leather or rubber case similar to a bicycle tire. As the train comes along, the enigneer can reach out and catch the hoop-shaped case on his arm. Evidently the

size of the metallic staff must be decreased from its length of 20 inches and diameter of 1 inch, if it is going to be safe to pick it up at thirty miles an hour. The present size resembles a lead pencil. The development up to this time is really quite simple, but the system is applicable only to absolute blocking.

In order to meet the question of permissive blocking some changes were necessary. The principle of a divided staff was reverted to. In order to give a train a follow-up order, the operator at the exit end of the block is requested to unlock the machine at the entrance to the block. A staff is then removed as before. The end of the staff is shaped like a key, and unlocks a cabinet of tablets. The first train to enter a block is given a tablet. The next train to follow it is also given a tablet. This distribution of tablets is continued as long as trains are granted permissive movement in that direction. The last train to enter under the permissive block rule takes the remaining tablets and staff with it. Not until all of the tablets and the staff are placed in the machine at the exit end of the block, can either machine be unlocked.

There are certain conditions which it would be necessary to meet on some railroads before the above system would be applicable. Let us consider, for instance, the case of a pusher grade extending part way through a block. When the pusher engine has reached the top of the grade, it desires to return to the entrance of the block at the foot of the grade. The train itself, however, desires to proceed on to the exit of the block. The condition could be met in this manner. When the operator at the exit end of the block receives the request, he unlocks the machine at

the entrance to the block. The operator at the entrance then takes out two staffs. One he gives to the engineer on the through train and one to the engineer on the helper engine. The engineer on the through train acts under ordinary orders, giving up the staff at the exit of the block and proceeding as before. The helper engine, however, goes to the top of the grade, and then returns to the entrance of the block, where the staff is returned. When each staff has been handed in, but not until then, either machine can be unlocked.

In order to meet the problems of open switches along the line the following method is in use. Each staff acts as a key for the switches on that particular block. When it is desired to open a switch the engineer gives the staff to the brakeman. The brakeman unlocks the switch and opens it. As soon as he unlocks the switch, however, his staff is fastened in the lock. As long as the lock remains open, that long will it be impossible for the staff to be removed from the switch. The purpose of this requirement is to keep all switches closed in front of a through train on the main line. When the engineer has a staff, he knows that that staff is the only one out, on the block. He also knows that a switch lock must have a staff in it in order to be open. Possessing the staff, as he does, he is confident that all switches in his block are closed.

One of the most valuable applications of this principle is in the case of a siding. If a block is pretty long, and there is a siding halfway through the block, it is often desirable to send a train as far as the siding and hold it there until another train passes it. The staffs of any block are duplicates of each

other only every fifth block. It is thus necessary for an engineer to carry a staff four blocks, in order to find a switch that it fits. This safeguard proves effective protection against a malicious use of the staffs.

In both the train staff system and the Sykes system, the work of moving the signals is by hand. Here the personal equation is present, although to a less extent than in the case of the telegraphic block. If a system could be devised, then, where the operation of the signals would be dependent alone upon the automatic features of the apparatus, with absolutely no regard for the work of man in its operation, and only turning to man for its maintenance, we would have an automatic block system. It is an attempt toward such an end that the automatic block signal system has been developed.

AUTOMATIC BLOCK SYSTEM. The automatic block signal system usually consists of batteries, relays, signals, current conductors and the signal movers. The signal mover may be either compressed air apparatus, or low voltage motors with corresponding local circuits to operate them. The compressed air system is called the electro-pneumatic, while the latter system is known as the all-electric. The current conductor may be either a set of wires along the telegraph poles, or it may be the rails bonded together. The most common method is to use a track circuit, where the rails at each joint are bonded together, producing a connected conductor. This gives a big saving of installation cost over the method of using wires on the telegraph poles.

An analysis of the majority of automatic block signal systems will reveal the following essential parts. The "run"

is divided into a number of blocks from one-half to two miles in length. At the entrance to the block is a relay. The two parts of the relay are connected to the two rails. Each rail joint is bonded, while all possible places of short circuits between the two rails of the track are insulated. A battery is connected across the rails at the exit end of the block. When the current is flowing it passes across the battery, along one rail to the relay, across the relay and back along the other rail to the battery. When a train comes along it short circuits the battery, by sending the current between the rails, through the car wheels and axles in place of through the relay. This cutting-out of the relay causes the armature to drop, and establishes a local circuit at that point. If the all-electric system is used, this local circuit runs a motor, and the motor runs the signal. In discussing the automatic block system, explanation will be directed to the track circuits, including relays and batteries; to the signal indicators, touching on both the semaphone and enclosed disc; and finally to the subject of signal movers.

The track circuit consists of the rails, the relays and the batteries. On the average steam railroad the rails are fastened together by a bolted joint. This joint does not make a good conductor, for with rusty nuts, or loose bolts the electric connection between the rails is very poor, and the resistance is so very large as to make joint quite unreliable. It is customary, therefore, to bridge across the joints by the use of bonding wires. Bonding wires are fastened from the web or flange of one rail, across the joint, to the corresponding part

of the next rail. These wires usually consist of material a few inches longer than the joint. The wires may be fastened to the rails by welding, although the more common method on steam roads is to make the connection with a fit-driven rivet. It is stated that the track circuits are cheaper to install and maintain and are more immune from the ravages of lightning and wind, than are those circuits carried by wires along the telegraph poles. These advantages alone, probably, are sufficient justification for the adoption of the track circuit over the wire circuits.

The batteries used on the track circuits are usually gravity cells. The gravity cells may be used for a long time without a large cost. Their circuit, however, must be closed, for when the gravity cells are left on an open circuit, the constituents of the cell segregate, due to the difference in their specific gravities, and the strength of the cell is thus seriously affected. It is not meant to be inferred that the gravity cell is the only type of cell used on track circuits, for storage and other forms of primary cells are in use. What is meant to be emphasized is that the cheap cost of maintenance makes it almost universally adopted.

The establishment or breaking of a weak current may be used to do heavy work, indirectly, by the use of the relay. As electricity flows through a coil of wire, the coil becomes an electro-magnet. One side of the coil may become the positive pole, and one side the negative pole, depending upon the direction of the current. A relay consists of two coils of this nature. The weak current is sent through these coils and a temporary magnet is established. As soon as the current is broken,

the magnet is also broken. The principle, then, is to put a piece of steel in front of the magnetic coils. When the weak current goes through the coil, it acts as a magnet, and draws the steel bar to it. When the current is broken the steel bar is jerked back to its original position by a spring. This movement of the iron bar, then, is used to make and break a local circuit. This local circuit is a stronger circuit than the track circuit. Another point in connection with the relay is that it acts as a resistance. It can be shown by mathematical proof that the greatest value may be obtained from a battery when its internal resistance equals the external resistance. In order to bring about this condition, the coils of the relay increase the track circuit resistance until it equals the resistance of the battery.

Following quite logically upon the subject of the track circuits comes the explanation of the "signal movers". Due to the fact that this term is hardly a technical one, it will be defined. The movement of the signal indications is not usually done directly by the track circuits, as was alluded to in the preceding pages. There is either an electric motor, or an engine of some description, which throws the signal. The term "signal mover", then, may loosely be defined as the apparatus which is used directly to throw the signal. The electro-pneumatic will be the first form discussed.

In the electro-pneumatic system the power to pperate the signals is either air, or gas. The principle is this: Upon the movement of the armature of the relay, caused by certain movements of the train in the block, the signal indication is

required to be changed. A pin-valve fastened to the movable armature opens as the armature moves. The opening of this pin-valve closes the exhaust valve of the apparatus, and simultaneously admits air into a cylinder. The piston within this cylinder is stationary, but the cylinder is movable. Therefore, with this increase of pressure within the cylinder, the cylinder moves, and in moving changes the indication of the signals to which it is fastened.

If it is required to have a three position signal in place of a two position signal, two cylinders are used of different sizes. One cylinder fits upon the top of the other one. By a mechanical device the top cylinder moves the signal from clear to caution, and the lower cylinder moves the signal from caution to danger. These two separate movements are used to keep the indications independent. A failure of the clear indication sends the signal directly to danger, avoiding any chance of the cylinder catching in the caution position.

In the operation of the signal it is very essential that the apparatus be kept as dry as possible, for a quantity of water inside of a cylinder would obviously cause slow and undecided movements. Leak wells are therefore placed along the pipe lines to collect the condensed moisture.

In the operation of this type of electro-pneumatic block it is necessary to have a compressing station every twenty-five miles. This is probably one of the features which encourages its use for terminal practice only.A two-inch iron pipe is run out from the source as a main. This pipe is often encased in a wooden protector, and buried underground. Taps

are run from the main to the signals when necessary. The pressure is from sixty-five pounds to eighty pounds, and proves a large enough force to give decisive movements, a requirement most essential to the practice of good signaling.

In the electro-gas system, as stated in the 1911 Signal Dictionary, the source of power is liquified carbonic acid gas. This gas comes in a tank under a thousand pounds pressure, and is reduced by valves to sixty pounds pressure before using. Each tank contains sufficient gas for several hundred movements. The tanks come from a central station, and an extra one is kept at each block to be prepared for an emergency.

The actual operation of the machine is very similar to the electro-pneumatic. The cylinder and piston are made a machine fit. The piston is stationary and the cylinder is movable. This gives a solid cylinder head and avoids the possibility of water getting in from the outside. The high pressure gas goes through an interesting apparatus to prepare it for working pressures. In this process of reducing the pressure from one thousand pounds to seventy pounds, the gas from the supply tube is turned into the expansion cylinder. The pressure of the gas as it enters here is kept constant by automatic mechanisms. As the pressure decreases the valve automatically introduces a supply from the tank. When the pressure in the expansion tank gets up to the desired value, the valve closes. There are two gages on the machine, one for high pressure and one for low pressure. By means of the readings on these instruments the valves may be adjusted.

We have dealt rather exhaustively upon the electro-

pneumatic system as a "signal-mover". The other type of "signal-mover", the one in greater use, perhaps, on cross country blocking, is the all-electric. The track circuit of this system is the same as that of the electro-pneumatic. Upon the movement of the armature in the relay, however, in place of a pin valve being opened, an electric circuit, called the local circuit, is closed.

The energy of the local circuit comes from primary batteries, as a rule. This current is considerably stronger than the track circuit. The voltage needed to overcome resistance is also greater, and the cells are, therefore, connected in series.

The local circuit consists of a relay, a motor, a set of batteries and the accompanying wires. There are several types of motor which can be used, but from the nature of the source of power, it is most economical to use a low voltage machine, usually about ten volts.

The mechanism may be either at the top of the mast, or at the bottom. Opinion is divided concerning the relative qualities of the two systems. It is fairly certain that with the mechanism at the top of the mast there is less lost motion during the movement of the signals, while the base-of-mast method offers the advantage of facility of maintenance. There is a variation in the number of batteries used on the signal circuit. Sometimes as many as twelve are used, although eight is an average number. If the circuit is not too long, the track circuit can be used to operate the signal. This applies to a single home signal, however.

The signal indication may be one of several forms,

although the enclosed disc, or the semaphore, is usually adopted. Since the semaphore is a position signal, while the disc is a color signal, the former is usually preferred. The semaphore consists of an arm fastened to the mast. The indication which the signal conveys is given by the position of the arm. Horizontal represents danger; vertical, clear; and if a three position system is used, forty-five degrees to the horizontal represents caution. Glass discs are set in the counterweight of the arm, and the night indication is given by the reflection of a lantern through these differently colored glasses.

The disc signal, on the other hand, is a strictly color signal. There is a round hole, about eighteen inches in diameter, in a box shaped like a banjo. Inside of the box are several discs, or movable arms. These arms are circular; and by their movement, which is actuated similarly to the movement of the semaphore arms, the indications are given. When there is no disc in front of the hole, the white back of the box is shown, and the signal is clear. The danger or the caution signal is given by the corresponding color disc being moved in front of the hole. It might be said that the disc is made by stretching a piece of colored silk over the ring of the arm. The danger of the glass over the hole getting covered with wet snow, or of the sun reflecting on the glass in such a way as to cloud the view, are the distinct disadvantages of the system.

IV. COMPARISON OF THE VARIOUS SYSTEMS.

Entering directly into the discussion of the telegraphic block system as we are now to do, we are immediately concerned with the question of the personal equation in signaling. The telegraphic block is peculiarly susceptible to the influence of the personal equation, both in the giving and in the receiving of the indication. Before going further, however, let us consider the meaning of the phrase "personal equation."

In the testing of an electric apparatus, certain data are first obtained whereby it is possible to foretell the operation of the machine under varying conditions. With different values of speed, voltage or current, definite results may be predicted. The laws of electricity are so precise that the exact relation of all variables is positively known. Curves representing the relation of these variables are called the "characteristic curves" of that particular machine.

On the other hand let us consider the results obtained by different men when called upon to perform the same problem. If it is a requirement to report the amount of material in a yard, the answers will present remarkable variations. One man may calculate the amount of steel closely, but be quite incorrect upon the amount of timber. The next man may vary in another particular. The various impulses which influence a man in his decisions or actions, are the things which distinguish that man from his neighbor. These variations are the essential characteristics of his work, and are technically known as his "personal equation." If he is careless at times, the personal equation is

correspondingly affected.

The analogy with the characteristic curves of the electric machines should be apparent. This seemingly lengthy discussion of the personal equation can be justified on the grounds that the relative merits of the various systems of signaling are greatly affected by the extent of the application of this "personal equation."

With the telegraphic block orders are sent back and forth by wire. In the very first instance, the order may be misinterpreted. If an operator receives a long message, he may be prone to abbreviate it in copying it down. This is especially true if he did not receive the exact wording of the items. It is not infrequently stated that new operators, fresh from the school of some railway office, are proud of their ability to receive orders, and so they receive as fast as possible, filling in the details after the communication is over. The seriousness of such practices can easily be imagined.

The telephone has been suggested as a remedy for this over-confidence which many operators are inclined to show. Undoubtedly, under such a system competition of speed would disappear, and the increasing use of the telephone in train-dispatching is indicative of this result.

It is also urged that since the pay of the operator at the average block station is low, most operators are using the position as a stepping stone and intend to leave in a short time. This condition offers continual variation in the routine of the work, and requires breaking in a new man quite frequently. The stations may thus be filled with operators of poor or medi-

ocre ability, men who are either not capable of advancing, or, if capable, they have not the ambition to merit such progress. In either case they may make poor assets to a safe and efficient operation of railway traffic.

Suppose we replace the telegraph key by the telephone receiver! Is the condition bettered? As stated above, rivalry of speedy messages will disappear. On the other hand women may be employed. The new position may also offer a place for cripples, men who have become injured in railway service, and whom the railway is repaying with a "soft job." Finally, the operators may be lads who have not acquired the calmness and experience demanded during busy hours. Thus it is possible that the new method of communication will introduce help lacking in experience, in character, or in moral backbone. With all of these possibilities of weak spots, is it not probable that some one operator will be unfitted for his job? If he is, what is the effect on the system? Truly, no block system can be more efficient, or more safe, than its weakest block.

Absolute inattention to work is also possible. If there are three operators at a station, there will be two off of duty all of the time. About six o'clock in the evening, the time when a shift may be made, the two idle men will both be awake, and, perhaps, there will be fooling in the office. Knowledge of human nature will emphasize the probability of the operator becoming inattentive to his work. One careless moment, and a toll of death and money may result. It is not an infrequent thing to see the active operator entering into some heated argument with the idle man. On several occasions I have seen

a fast game of "black-jack" played in the office. The operator on duty had the deal, and it is a wonder that he tended to his work as well as he did.

At another time an operator had to stop a fast transcontinental train at the station simply because he did not have clearance for it. The operator had been repairing his phonograph for a minute or two, and he did not realize that the flier was due so soon. Hardly had the deep tone of the whistle come rolling down the canyon when the train came around the curve into full view. An extra worktrain was coming up the grade, and possibly a serious accident was barely averted.

Even at best we are confronted with these conditions in considering the telegraphic block system. The operator may fall asleep at his post, or he may be drunk, or sick, or otherwise incapable of performing his important duty. One such an occurrence and a bad accident may result. The telegraphic block system is really an application of the personal equation to railroad signaling. The reliability of the first step in signaling, the step of giving the indication, is greatly impaired in such a system.

The controlled manual offers considerable improvement over the inherent disadvantages of the telegraphic block. Until the introduction of this system the permission of the next operator was given by wire, and there was no effective check upon the work of either. With the controlled manual system the mechanical check of the locking device, as has been explained previously, makes the operation of the system reasonably safe.

The weak spots in one man's personal equation may not

occur at the same time as those of another man. One man may be most attentive while his neighbor is temporarily careless. What is the significance of this check? The mechanical devices insure that the two men will check each other upon the movement of the signals, and unless the machines are tampered with it is mechanically impossible for a clear signal to be given while a train is in the block. The question is, will these checks prove absolutely thorough, and the answer is that they probably will not, on the basis that when a man knows that another man is looking over his work, he instinctively tends to lose responsibility. It is thus possible for a mistake to occur, although it is far less probable than in the telegraphic block. Of course there is nothing to prevent the engineman from running by a danger signal in either case.

With the automatic block system, the personal equation and downright carelessness are of great importance in their effect upon efficiency. It is true that the signals are all thrown by the train itself, and, from this consideration it would appear that the human equation did not enter at all.

There are really three distinct parts to the process of efficient block signaling. One part consists of operating the signal, another part consists of interpreting and obeying that signal, and the third part consists of its proper maintenance. We have already considered the operation of the three systems of signaling. It has been pointed out that the operation of the telegraphic block was dependent entirely upon the personal equation, and that the controlled manual was dependent to a partial extent upon it. Furthermore it was shown that the automatic block was independent of the personal equation. With the interpretation

and obedience of the signal orders, let us consider the effect of the personal equation.

With the telegraphic block, the engine-runner has to receive his orders from the operator directly. The engine-runner is required to get the clearance card before entering a block in order to turn it in at the end of his run. He will not proceed, therefore, until he has received his orders to do so. He can be brought to account for a direct disobedience of this rule, however; and as this is a malicious step he will not take it deliberately. He is certain to be reported if he should disobey the signal. The same may be said of the controlled manual system. The operator will report disobedience of the danger signal immediately, for his own protection. The matter of correctly interpreting the signal indication is really the same in all three systems. The question of the engine-runner becoming suddenly disabled is likewise unaffected by any of these systems.

All automatic signals are so wired and counterweighted that any ordinary breakage of the apparatus or failure of the circuits will send the signal to danger. It is a strict rule with the engine-runners that they must come to a stop whenever a signal is at danger, wait an interval of a moment or two, and then proceed cautiously until the next clear signal is reached. Since there is nobody to check the engine-runner, in order to insure that he actually stops in such a case, he may slow down to a few miles an hour without even stopping. There is a particularly strong temptation to do this in case there is any difficulty in maintaining his schedule. The results of such practice are certainly most dangerous. There are several disastrous wrecks

of recent occurrence to remind us that it is not uncommon practice to do this, and the engine-runner is only partially to blame. The public insists upon trains running fast and being on time regardless of weather. The railroad officials, in order to maintain the prestige of the road with the public, admonish the engine-runner in case of train delays. The outcome of this anomalous situation is that the engine-runner takes the chance of running by a danger signal now and then, until, finally, a wreck ensues. This aspect of the subject will be again emphasized in the conclusion.

The effect of maintenance upon the safety and efficiency of the block signal system remains to be discussed. With the telegraphic block the apparatus is limited to such a small quantity that the maintenance is not of great weight. The working of all nearby signals can be tested by the operator during a few minutes of his off-duty hours. With the controlled manual there is far more to be attended to. The apparatus must be inspected. The lights should be in working order and everything should be ready for correct operation at any time. There is, however, this check in the manual systems. Should the lights be out, or working poorly, the operator can see them. The advantage is that since the operator is within sight of the lights, he can attend to them.

The maintenance of apparatus on the automatic block signals assumes a far more serious aspect. There is no human check upon the condition of operation for hours at a time. The circuits, batteries, and machines are all in great need of the most careful attention. There is extreme difficulty in obtain-

ing the right kind of men for this work, as they must perform their duties in all kinds of weather with little effective supervision.

It is very necessary that the batteries work correctly. The cells must therefore be carefully inspected, and any trouble promptly remedied. If the maintainer understands the principle upon which the gravity cell works, he will know that the two solutions should not be mixed. He will also know how to get at little breaks in the line which otherwise might be overlooked. If the mechanical apparatus is out of order, the automatic checks of the mechanisms usually afford protection against accidents.

Since maintenance is so very important in its proper operations, the automatic block signal system should be cared for frequently and regularly. It is particularly important that the lamps be maintained in burning condition, as many of the signals are located at obscure points along the road where otherwise they might be overlooked.

As this discussion would not be complete without taking up the factor of cost, it will now be dealt with. The federal "nine-hour law" which was passed a few years ago has had an important bearing upon signaling. This law requires that any railroad doing interstate business must not work an operator more than nine consecutive hours. The blow which this law strikes at the controlled manual systems is most serious. Formerly it was possible to have two shifts per day, but it is now necessary to have three in order to comply with the law. The cost of operating the controlled manual system with this extra shift is increased nearly 50 per cent.

The cost of installation of each of the several systems can be determined with a fair degree of accuracy. Of course in the controlled manual signal towers may or may not need to be erected for the work. This item, which will not be considered below, because of its variant character, is an argument against the controlled manual.

In the presentation of the following data the writer is indebted to Mr. W. H. Elliot of the Milwaukee system, to Mr. J. B. Latimer of the Burlington system, and to current editorials in the Signal Engineer. Capitalizing the installation cost at 6 per cent we find that the yearly charge for one mile of signal system, including the cost of installing, maintaining and operating is as follows:

Telegraphic Block...........	$ 58.27
Controlled Manual...........	165.00
Automatic Block.............	72.00.

The cost of installation of the automatic block is about $400 per mile of single track, while the cost of the controlled manual is between $80 and $100 per mile. The greatest factor in the operation of the controlled manual system is the operators' pay. Since the nine-hour law has been passed, the controlled manual has become very expensive to operate.

The question is frequently asked, "What is the present tendency of the railroads in regard to the various signal systems?" The answer will be brought out in the following discussion:

Number of Miles of Railway in the United States Operated by the Controlled Manual and the Automatic Block Systems.

	1908	1910
Manual Block.............	47,875 miles	56,078 miles
Automatic Block..........	10,803 miles	20,334 miles

From this table it will be seen that the automatic block has increased 100 per cent in the period 1908 to 1910.

Many railroads have been replacing the controlled manual system with the automatic block system. On the Pennsylvania railroad between Pittsburg and New York City there are at present 77 miles of controlled manual. In the report for the year ending January 1, 1913, it was stated that with the exception of this 77 miles the entire main line from New York to Pittsburg was under automatic block signals. It stated, further, that while this 77 miles was still under controlled manual, they hoped "to care for it as soon as possible." This spring the Chicago and Northwestern is completing a strip of automatic block installation which runs from Evansville, Wisconsin, south thirty-five miles. At the present time the New York, Chicago and St. Louis is putting all of their lines in Indiana under automatic block signals. One interesting point in this latter installation is a clause in the operating rules requiring a two-minute wait before a train may pass a home signal at danger.

The staff system is not extensively used in this country. There are, perhaps, six installations in all, none of them being over 100 miles long. In the Cascade Tunnel in Washington, the Great Northern railway has used the electric train staff system for a number of years. They use the divided staff, the engin-

eer taking one half and the flagman the other. They use a semaphore to signal when a staff is ready to be picked up. It is expected that the system will be extended eastward to Leavenworth, Washington, and westward to Skykomish, Washington, making the total distance fifty-seven miles. The solid staff will replace the divided one now in use.

The train staff system is used in America only under some such special conditions as noted above. The Southern Pacific is at present installing a staff system at Great Salt Lake. The salt water causes so very many short circuits during the wet weather that a track circuit is impossible.

V. CONCLUSION.

Up to this point of the thesis we have been chiefly concerned with the details of the various systems. We have discussed their origin, history and construction. We have also made concrete comparisons between them. Let us now consider whether the extensive growth of the automatic block is justifiable.

The people of the commonwealth are demanding federal requirement of automatic blocks on all passenger-carrying railroads. The plea is making a strong platform for politicians, and numerous committees are seeking data for Congress thereon. It seems certain that in the near future block signaling will be required by law.

If the automatic block system, as it is now developed, were universally adopted, it is well for us to realize just what reduction in the number of accidents would likely occur. Colonel Henry G. Prout has made a most thorough and commendable investigation of the question of railroad accidents, and his conclusions are summarized in this one sentence. "If every foot of track in the United States were blocked, our train accidents would be reduced almost 50 per cent." Since, however, the train accidents represent only 22 per cent of the total fatalities, the reduction in the total number of persons killed each year in train wrecks would be only about 11 per cent.

The people are demanding too much of the signal systems. Their demands are probably based upon the reports they read from English railways. They recall that the English railroads did not kill a man in 1908, and that in each year the fatalities have

been consistently low. They draw the illogical conclusion that the number of our fatalities could be the same. The conditions in the two countries, however, are not the same. Since the act of 1839 the Board of Trade of Great Britain has had the power to condemn any railroad crossing which is not properly protected. All grade crossings must be protected by gates, which are normally closed. Here are items which materially cut down the death toll. Many uninformed molders of public opinion, however, demand that the block signal systems should do for America what the rulings of the Board of Trade are doing for England.

In addition to these demands for safety, the people demand speed. They invariably take the faster train, when given the choice. By their very patronage of fast trains they make their demand effective.

Statistics from automatic block systems show that out of every 225,000 indications given there is one wrong movement. Remembering also that this one incorrect signal movement may not cause a wreck, it appears that the principal cause of American railroad accidents, in so far as they are due to faults of signaling, are not due to defects of the mechanical design of the automatic block signaling, but to human carelessness.

As regards human carelessness, we may say that a more rigid discipline among our railway employees is a crying need at the present time. Engine runners disobey important rules continually in order to keep to their schedule. Bringing in a train late usually requires an oral and sometimes a written explanation. If an engineer has to break a rule to be on time, he will very likely not be brought to account for it, with this one exception.

The exception is a wreck. When a man's reputation and standing with his employer are based upon the results he obtains, as are the engine-runner's, it is no wonder that such conditions lead men to become careless of rules. An additional weight to this carelessness will be added by the confidence that the average engine-runner has in the automatic system. The very fact that it is "automatic" makes him less careful than he otherwise would be.

The application of this carelessness on the automatic block is found when the engine-runner runs by a home signal at danger. There are two remedies offered for this lone draw-back to the automatic block system. One remedy is the placement of derails, or automatic stops at the home signals. The derail is a piece of steel which fits upon the rail and throws the car wheels off onto the ties in case the signal is at danger, It is inapplicable to high speeds. The automatic stop is a device whereby the engine is brought to stop by means of certain levers on the engine. One of the levers is fastened to the brakes, and throttle. Another hangs below the engine frame. When the signal goes to danger a bar is raised between the rails. This bar catches the lever and thus shuts off the steam and applies the brakes.

The second remedy is the education of the men. They should not only understand the technical requirements of good signaling, but they should realize their duty to the railroad and to the people. They are entrusted with the lives of every passenger on the train, and they should exhibit as much regard for the travelers as the captain of a ship 1,000 miles from shore. Pamphlets may be used to instil this spirit of duty, or officials may give talks to the men at the meetings of their brotherhoods.

Then again the idea of making up time in bad weather or otherwise taking chances in order to get the train in on time should be discouraged, and every step which makes for caution should be welcomed by the officials. The question is surely an important one, and is likely to command more and more interest until it is solved.

The automatic block signal system has justified both its extensive growth of 100 per cent in the last four years, and its replacement of the controlled manual on lines like the Pennsylvania Railroad and the New York Central Railroad, on the following grounds.

Considering both the cost of installation and the cost of operation and maintenance, it is the cheapest system.

Considering the question of safety, it offers the best opportunities of any system, and whatever it has lacked in this respect in the past has been due almost entirely to a mistaken effort to satisfy the speed-craze of the American traveling public, rather than to any inherent mechanical defect in the system.

Considering the question of efficiency, it is the best because it is practical to have shorter blocks, and because it is not necessary to slow up at the end of each block as with the Sykes system and with the electric train staff system.

In spite of both its inelasticity to varied train movements, and its tendencies to make employees careless, it is still the most desirable system; and the writer has come to the conclusion that the growth of the automatic block system on American railroads is entirely justified, and that its extensive adoption is of a substantial nature.